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A SIMPLE DEMONSTRATION OF CORROSION CELLS

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Key Words: Corrosion, Galvanic Cell, Polarization

Prerequisite Knowledge: Concurrent with classroom lectures on corrosion theory and phenomena, subsequent to laboratory and classroom discussions on cold working and the microstructural heterogeneity of most metals.

Objective: Reinforce and enhance the understanding of galvanic cells, anode and cathode reactions and polarization phenomena.

Equipment and Supplies:

(8) Common Nails, at least 16d size (at least 90 mm long)
(1) Galvanized Nail, same size (Alternatively, another mild stee nail and a strip of zinc can be substituted.)
Bare copper wire or strip
Tin wire or strip, alternatively lead wire or strip
(9) Glass test tubes with rubber stoppers
Test Tube Rack
Distilled water
Tap Water

Procedure:

The instructor should put the following materials into test tubes two days in advance of the laboratory session:

Tube 1	Clean steel nail covered with tap water
Tube 2	Clean steel nail covered with tap water, boiled to drive off dissolved oxygen
Tube 3	Clean steel nail covered with distilled water, boiled to drive off dissolved oxygen
Tube 4	Steel nail, as received, covered with tap water
Tube 5	Clean steel nail partially immersed in tap water
Tube 6	Galvanized nail, one side ground flat, (alternatively, a clean steel nail, wrapped with a narrow (3-5mm) strip of zinc coiled into a helix) covered with tap water
Tube 7	Clean steel nail, wrapped with copper wire or strip, covered with tap water
Tube 8	Clean steel nail, wrapped with tin wire or strip, covered with tap water
Tube 9	Clean steel nail

All tubes should be stoppered, placed in a test tube rack, and left undisturbed.

During the laboratory session, students should inspect each of the test tubes (CAREFULLY -- DO NOT SHAKE OR JAR THE TEST TUBES IN ANY WAY!). Observations should be noted regarding the appearance of the materials in each of the tubes.

Students' reports for this laboratory session should contain all of the following elements:

Summary

Description of Experiment
A sketch of the appearance of the nail in each test tube with all elements carefully and completely labeled.

Analysis of Data
For each test tube, the student should identify:
- any evidence suggesting that a galvanic cell is operating,
- the anode and cathode regions,
- the most likely chemical reactions occurring at the anode and cathode.

Conclusion
A concise restatement of the necessary conditions for galvanic corrosion and the bases for anodic and cathodic polarization.

Remarks regarding which of the cells were most informative in supporting the theory of corrosion discussed in classroom lectures.

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<u>Interpretation of Corrosion Cells</u>:

Tube 1 Galvanic corrosion occurs when two materials of different solution potential are electrically connected and situated within an electrolyte. For the nail in this test tube, the presence of rust on the head, the point, and, less distinctly, on the ridges under the head along with the absence of rust on the shank are evidence of a galvanic reaction. The tap water is the electrolyte. The rusted areas, being more severely cold worked than the shank, are anodic regions. The shank is the cathode.

Tube 2 All of the elements needed for corrosion are present--anode, cathode and electrolyte. However, there is little evidence of rust because the water does not contain a large quantity of the dissolved oxygen necessary to form $Fe(OH)_2$. The anode and cathode areas are the same as in Tube 1.

Tube 3 This cell exhibits even less reaction than Tube 2. Because the distilled water is deficient in ions, it is a poorer electrolyte than tap water. The galvanic reaction is suppressed.

Tube 4 The extent to which less rust is present here than in Tube 1 depends on the amount of grease and wax remaining on the surface from the nail forming process. This coating temporarily inhibits the current flow necessary for corrosion. Oxygen concentration cells quickly form at scratches in the coating, separating it from the metal. Soon the galvanic action becomes more uniform, and the appearance becomes similar to that of Tube 1. A galvanic cell is operating.

Tube 5 The nail has a dense ring of rust at the waterline. Close observation will show pitting attack of the steel just below the waterline. The corrosion cell results from the difference in the oxygen concentration at the water surface and the concentration at some depth. The cathode region occurs at the surface and the anode region is just under the surface.

Tube 6 The exposed steel on the galvanized nail is covered with bubbles. Of the metals present, the zinc is the anode, and the exposed steel is the cathode. The bubbles are hydrogen gas produced by the cathode reaction:

$$2e^- + 2H_2O \text{ ----> } H_2 + 2OH^-$$

The hydrogen gas bubbles are evidence of activation polarization at the cathode which is slowing the rate of corrosion by forming a physical barrier to further reaction. A white precipitate, zinc oxide or hydroxide, may be visible at the bottom of the tube, further evidence that the zinc is undergoing oxidation. Of the metals used in this demonstration, zinc is the only one which is sufficiently anodic to displace hydrogen from water.

Tube 7 The nail is covered with the same pattern of rust as in Tube 1. The anodic areas are the head, the point and the ridges; the cathodic areas are the copper wire and, to some extent, the shank. The copper affords no protection against corrosion. In fact, it accelerates the corrosion reaction because the difference in galvanic potential between the copper and steel is greater than that between the two regions of steel having different degrees of cold work, as was the case with Tube 1.

Tube 8 The appearance is essentially identical to Tube 7. Even though tin is slightly more anodic than copper, it is cathodic to steel. There is no visual evidence of polarization. (If lead is substituted for the tin, the same comments apply.)

Tube 9 A galvanic cell is not operating because one of the necessary conditions is not met; an electrolyte is not present.

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Notes for the Instructor:

The use of common nails to demonstrate the principles of corrosion has been described by several authors[1-3]. The experiment described in two of the references is particularly interesting in that color indicators are added to the electrolyte to delineate the anodic and cathodic reactions. Phenolphthalein is used to indicate by the formation of a pink color the presence of hydroxyl ions formed by the cathode reaction:

$$4e^- + O_2 + 2H_2O \text{ -----> } 4OH^-$$

Potassium ferricyanide, $K_3Fe(CN)_6$, indicates the presence of ferrous ions by the formation of the dark blue compound, ferrous ferricyanide. The electrolyte employed is an agar gel which keeps the reaction products near their points of formation. The reactions can even be carried out in a flat-bottomed glass dish placed on an overhead projector. However, the preparation time for such a demonstration is more extensive because of the time needed to prepare the agar-based electrolyte.

We have found that our abbreviated version of the common nail corrosion experiment is elegantly simple to prepare, yet pedagogically efficient in that it directs students to make observations that focus on the elements of galvanic cells and basic polarization phenomena.

If a few simple precautions are taken, the corrosion cells will react to a stage at which the products, either rust or hydrogen bubbles, are easy to observe and interpret.

Buy big nails. This precaution ensures that the point and head are heavily cold worked.

Clean the surfaces of the nails with 220 grit silicon carbide sandpaper and wash in methanol. Alternatively, clean the surfaces by glass bead blasting. Metal wire or strip used to wrap the nail should also be lightly abraded to remove any surface film which might interfere with good electrical contact. Reserve one nail in its as-received condition for Tube 4.

When nails are wrapped with a strip of another metal, the helix should be tight enough to ensure adequate electrical contact between the two metals. However, ample space should be left between neighboring coils, so that the surface of the nail is readily visible.

If the test tubes are of a heat-resistant glass, the water can be boiled directly in Tubes 2 and 3 with the nails in place. The tube should be stoppered immediately to prevent contact with the atmosphere.

If lead or tin strip is unavailable, it can be made by pouring a small melt onto a steel block, hammering the solidified metal to a thickness of about 1.0 mm and then cutting off ribbons with tin snips. If a small rolling mill is available, especially one with grooves for making wire, the task is much easier. Be sure to skim the dross off from the melt just before pouring.

The galvanized nail must have one side ground flat to remove the zinc coating and to expose the steel. Use a pedestal grinder and grind deeply into the nail so that a large area of the steel is exposed. When the grinding is finished, clean the ground galvanized nail with 220 grit sandpaper and methanol.

When all of the test tubes are filled and placed in the rack, set it as close to eye level as possible, and post a fearsome sign prohibiting any disturbance. During the laboratory session, encourage students to rotate the tubes gently and inspect all surfaces. The corrosion products are surprisingly secure; with some care they can survive being passed around a classroom.

In those cells containing fresh tap water it should be noted that, as cold tap water warms up to room temperature, dissolved air may come out of solution and form small bubbles on the walls of the test tube and on the metal specimens. These bubbles may be dislodged, if desired, by gently tapping the tubes a few hours after the experiment is set up. Alternatively, the tubes may be left undisturbed so that the students can compare them to those tubes containing boiled water. The air bubbles should not be confused with the hydrogen bubbles which form on the exposed steel of the galvanized nail. The latter are generally much bigger than the former and will re-form repeatedly if they are dislodged.

After the laboratory session, discard the water and save all of the test tubes, nails, tin and lead strips and copper wire for the next semester's class. Rust deposits left too long are difficult to remove.

We have found that this demonstration graphically and easily illustrates the basic principles of corrosion. The following facts are clearly demonstrated.

Galvanic corrosion cells do not require the presence of two different metals. Regions having the same chemical composition but differing degrees of cold work are sufficiently different in chemical reactivity that an anode and cathode can occur in two regions on the same object.

The presence of two different metals promotes corrosion. Steel can be either the cathode or the anode depending on what second metal is present.

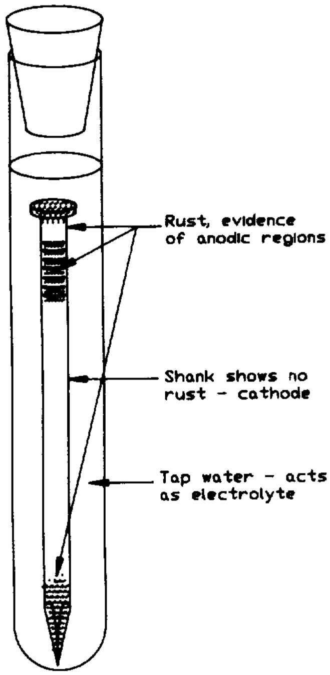
An electrolyte is necessary for corrosion.

Once materials for this demonstration are gathered, they are conveniently stored and reconstituted in subsequent academic sessions. Resurrecting the demonstration requires a brief cleaning of the surfaces and the addition of water. The ease with which this experiment can be set up using readily available materials makes it a valuable addition to the metallurgical teaching laboratory.

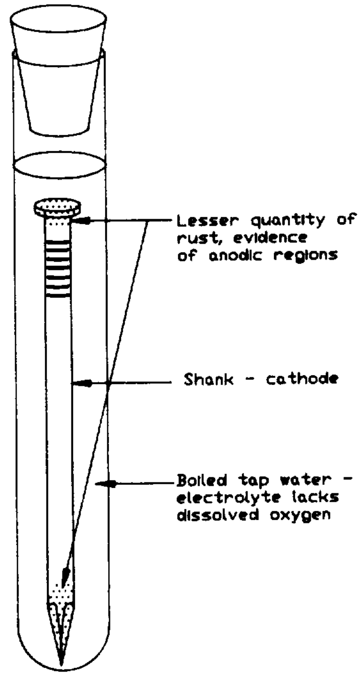
1. Corrosion in Action, The International Nickel Company, New York, 1977, pp. 15-18.

2. D. Eurof Davies, Practical Experimental Metallurgy, Elsevier, New York, 1966, pp. 118-122.

3. B.R. Schlenker, Introduction to Materials Science, Wiley, New York, 1969, p. 68.



Tube 1



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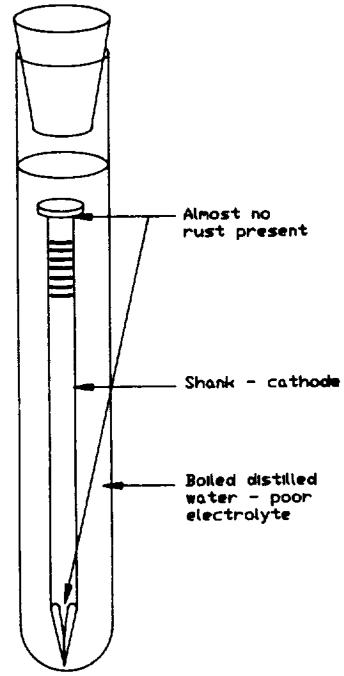

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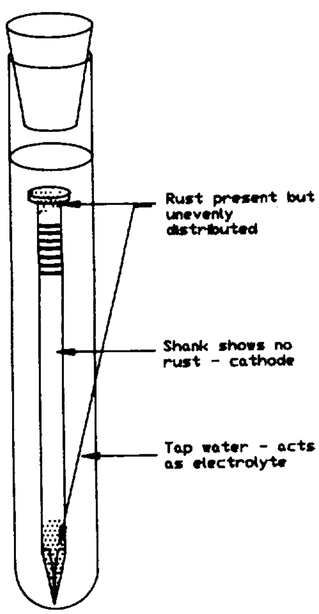

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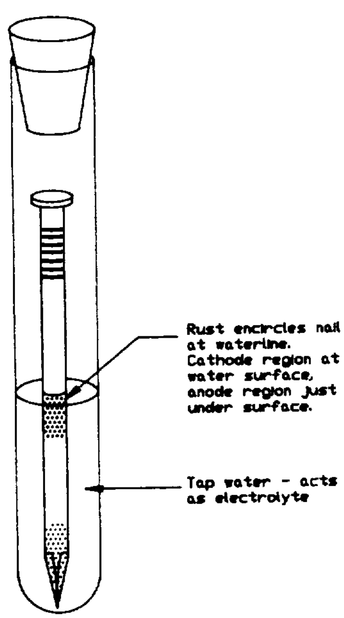
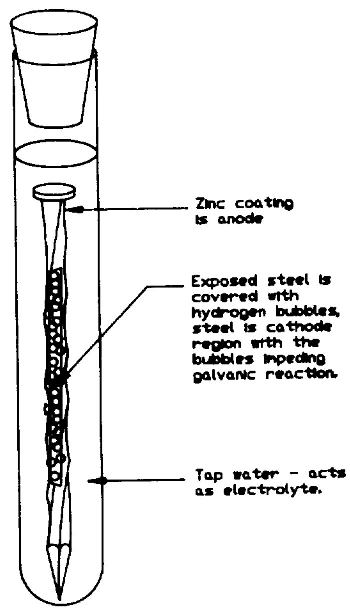
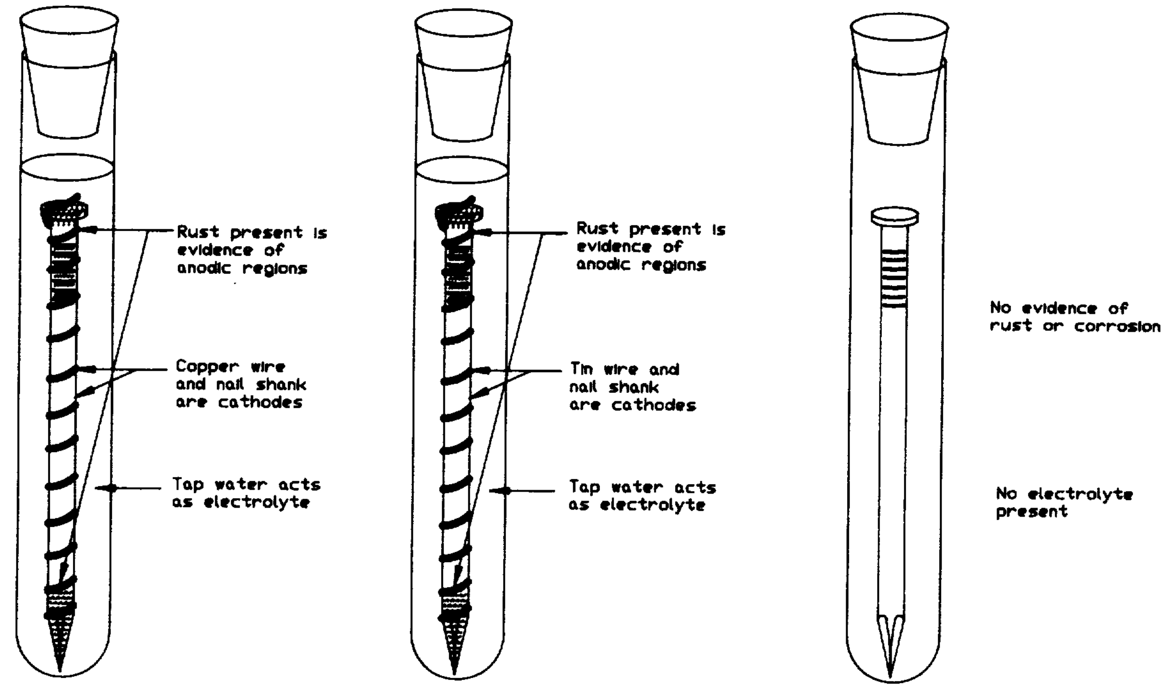


Tube 5



Tube 6



Tube 7 Tube 8 Tube 9